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GENERATOR BEARING SHAFT VIBRATION SIR ADAM BECK 1 GS, UNIT G5

Report No 87-139-K

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ABSTRACT

Vibration measurements on Sir Adam Beck 1 Generating station, Unit G5 have been recorded for a period of two years. Data collection has been facilitated by a computer based monitoring system installed under a contract with the Electrical Power Research Institute. Shaft vibration at the generator guide bearing is high in the summer with a marked seasonal variation. The vibration characteristics and history showing relationships with speeds, voltage, and temperature are reported. It is recommended that bearing vibration dependence on oil temperature as a single variable be investigated and that the generator be balanced before the summer demand peak in 1987.

job	file	date	report no.
27-307-431	825.43 (T)	June 4, 1987	87-139-K

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EXECUTIVE SUMMARY

GENERATOR BEARING SHAFT VIBRATION - SIR ADAM BECK 1 GS, UNIT G5

H.P. Koehler

A continuing surveillance of machine vibration levels has been maintained on this machine since the Monitoring for Predictive Maintenance system was installed in October 1985 for the EPRI monitoring contract. We have been concerned about the high levels of generator guide bearing shaft vibration which reached peaks of 19.5 mils peak-to-peak in 1985, and 15 mils in 1986. These levels must be compared with the bearing diametral clearance of 21 mils.

Extrapolation of vibration levels to determine when they might become unacceptable is complicated by a large seasonal variation, higher in summer than in winter. Despite this, levels in 1986 seem slightly higher than in 1985. Minimum filtered 1X shaft vibration, south was 9 mils in January 1986 and 11 mils in January 1987. This suggests the possibility of a higher peak in the summer of 1987.

The relation of vibration to speed, generator voltage, and temperature is discussed. It is recommended that a special test to verify dependence of vibration levels on oil temperature be conducted. Following that generator balancing should be scheduled at a suitable time before the 1987 summer peak load.

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TABLE OF CONTENTS

		Page
1.0	INTRODUCTION	1
2.0	HISTORICAL LEVELS AND THEIR COMPARISON WITH TEMPERATURE	1
3.0	24-HOUR VARIATIONS	2
4.0	VARIATION OF UNBALANCE ANGLE WITH TIME	3
5.0	MAGNETIC UNBALANCE	3
6.0	VARIATION OF SHAFT VIBRATION WITH SPEED	3
7.0	SHAFT ORBITS	4
8.0	MODE SHAPE	4
9.0	BEARING TEMPERATURES	5
10.0	VIBRATION LIMITS FOR GENERATOR GUIDE BEARING SHAFT VIBRATION	5
11.0	RECOMMENDED WORK AND TEST PROGRAM	6
12.0	CONCLUSIONS	7
REFERENCES		8
FIGURES		9

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To Mr. R.A. Wright
Manager - Hydraulic Plant Equipment
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GENERATOR BEARING SHAFT VIBRATION - SIR ADAM BECK 1 GS, UNIT G5

1.0 INTRODUCTION

1.1 This hydrogenerator was the first unit to be fitted with transducers and computer based monitoring equipment according to a contract (RP1745-12) with the Electric Power Research Institute (EPRI) entitled "Monitoring for Predictive Maintenance" (MPM). First tests were done in connection with the Canadian General Electric (CGE) company's "Special and Acceptance Tests" conducted in August 1985. The computer based Dynamic Data Manager (DDM)® was installed and the first baseline signature tests were conducted in October 1985. Since that time readings have been taken by station operators on a weekly basis and forwarded to the Research Division for examination and analysis.

1.2 A summary of the EPRI contract work is given in/1/, more detail on the test results are given in/2/. The EPRI contract work was completed in September 1986 with the exception of completion of the final report. First concerns about the high vibration levels were reported to Mr. J. Barbour of Hydraulic Plant Equipment in October 1986.

1.3 During the winter of 1986/7 shaft vibration levels at the generator guide bearing were considerably reduced and balancing was not recommended. A more recent examination of the results shows a strong seasonal variation in vibration levels resulting in recommendations for further tests and balancing before the summer peak in 1987.

1.4 Results of recent analysis are presented first, and then a summary of results from/2/ which are pertinent to the perceived vibration problem is given.

2.0 HISTORICAL VIBRATION LEVELS AND THEIR COMPARISON WITH TEMPERATURES

2.1 The plots of 1X shaft frequency vibration are illustrated in Figure 1. The cartesian graph shows the strong seasonal variation of the vibration amplitude. The polar graph shows that the phase angle of the vibration is relatively independent of amplitude and the difference in phase between the measurements from the south and east probes is nearly 90 degrees.

2.2 A sample of the DDM end-of-shift report taken on September 1, 1986 at 11:41 is shown on the next page.

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PAGE 2

VARIABLE	CURRENT	MAX/MIN	CURRENT	MAX/MIN	MIN STATUS
		T-R BRG ST-		T-R BRG EAST	
VIBRATION	13.5	15.0/12.8 MILS PK-PK	11.5	12.5/11.0 MILS PK-PK	OK
PROBE GAP	-10.3	-10.3 / -10.3 VOLTS	-8.9	-8.9 / -8.9 VOLTS	
1X AMPLITUDE	13.5	14.0/13.1 MILS PK-PK	10.7	10.9/10.1 MILS PK-PK	
1X PHASE LAG	330	332/330 DEGREES	242	244/242 DEGREES	
		T-R BRG ST-		T-R BRG EAST	
VIBRATION	0.0	0.5/0.0 MILS PK-PK	2.9	3.4/1.8 MILS PK-PK	ALERT
PROBE GAP	-22.3	-22.3 / -22.3 VOLTS	-5.4	-5.4 / -5.4 VOLTS	
1X AMPLITUDE	0.0	0.1/0.0 MILS PK-PK	0.3	0.9/0.2 MILS PK-PK	
1X PHASE LAG	55	356/ 3 DEGREES	249	298/249 DEGREES	

Note that the "current" values of the "1X Amplitude" have been plotted in Figure 1. The "Max/Min" values are reported for the preceding 24-hour period. "Vibration" values are larger than "1X Amplitude" values because of filtering. The turbine bearing south was inoperative at the time this report was taken. No further mention of the turbine bearing will be made since the levels are so small.

2.3 Figure 2 shows curves of river water temperture, cool oil temperature and thrust bearing metal temperatures versus calendar days (from Jan 1, 1985). Also shown by a dashed curve is generator guide bearing shaft vibration east filtered at 1X. The striking similarity of temperature and vibration curves suggests that the seasonal variation in vibration level may result from the change in oil film temperature which changes oil viscosity and oil-film stiffness.

2.4 Figure 3 shows the relationship between "maximum" and "minimum" unfiltered or "total" vibration compared with the "current" filtered 1X vibration levels. The results show that the vibration is largely at 1X shaft rotational frequency. There is no need for the "1X amplitude" to be between "maximum" and "minimum" curves and it is indeed lower at some times. The difference between "maximum" and "minimum" may represent some systematic daily variation or merely random variation from time to time.

2.5 What is of interest is that the daily or random variation is almost as large as the seasonal variation. If the daily variation results from field current changes, control of reactive power (field current) may be a means of controlling vibration levels. To examine this possibility a series of readings were recorded every hour for one day.

3.0 24-HOUR VARIATIONS

3.1 The automatic nature of the DDM makes it easy to take end-of-shift reports and the operators were requested to print an end-of-shift report every hour for a day, starting April 2, 1987 at 13:42. Figures 4 and 5 show the results.

3.2 Figure 4 shows minor random variation in output power. but a significant variation in reactive power with a night-time valley. Field current "indicated" by DDM is printed on the reactive power graph a few times. It is classed as "indicated" current because the DDM reading is significantly above

the true values. Bearing metal temperature, and vibration phase angles show insignificant variation.

3.3 Figure 5 compares filtered 1X vibration levels which are very constant and apparently little affected by the changes in field current. The right hand graphs compare "current" values both unfiltered "(total)" and filtered "(1X)". These results again show that the vibration is almost all at 1X shaft rotational frequency. "Maximum" and "minimum" vibration levels were not plotted since it was expected that the 24 hourly "current" readings would bracket the range of "maximum" and "minimum". They do not quite do that. For example max/min south and east at 13:43 on April 2 were 13.5/11.5 and 10.6/8.5 mils pk-pk respectively.

3.4 The polar graph is trivial with the "real" vibration values at 250 and 328 degrees. Note that the points at 0, 5, and 15 mils on the 0 degree axis were artificial reference points inserted to control the automatic scaling feature of the plot program used to prepare these results.

3.5 The diffence between the range max/min values of Paragraph 3.3 and the range of the 24 "current" readings is attributed to random statistics. The max/min range is determined automatically by the DDM from many thousands of readings whereas the range of "current" readings are from a small sample of 24.

3.6 The conclusion from this test is that it will be futile to try to control vibration levels by restricting field current (reactive power).

4.0 VARIATION OF UNBALANCE ANGLE WITH TIME

4.1 Figure 6 shows some preliminary graphs to show variation over the years. The upper right hand graph shows the relationship of south and east angles--at 90 degrees with little variation. The lower graphs show much magnified angle scales. There may be some sensible seasonal variation of "angle south" as seen in the lower left graph. The "angle east" variation shown in the lower right graph can only be classed as random, but note that the variation is very small.

5.0 MAGNETIC UNBALANCE

5.1 Despite the negative results reported in Paragraph 3.2 there were some earlier results which indicated considerable magnetic unbalance. Figure 7 and 8 give polar plots showing the effect of excitation level on shaft vibration magnitude and phase. Both graphs were taken during the CGE Special and Acceptance Tests. Figure 7 was taken first, during the unbalanced magnetic pull test (UMPT) as noted on the graph. Figure 8 was a normal open circuit test to determine the saturation curve.

5.2 Tabulating magnitude of change only, from zero to 100% rated output gives the following:

TEST	CHANGE SOUTH PROBE	CHANGE EAST PROBE
UMPT	9.5 mils pk-pk	11 mils pk-pk
Normal O.C. Test	13	6

The results seem somewhat inconsistent within themselves but they do show considerable magnetic unbalance.

6.0 VARIATION OF SHAFT VIBRATION WITH SPEED

6.1 There is considerable commentary on shaft vibration in/2/ at pages B1 to B14 and B30 to B35. Only the most applicable portions will be reproduced and discussed here.

6.2 Figure 9 shows Bodé plots of generator vibration. Phase angle and 1X filtered shaft vibration amplitude are plotted versus speed in rpm, for both east and south probes. Data is taken during a rundown, unexcited. All data is compensated for slow-roll runout by subtracting the vectors noted below the graph. The magnitude of the compensation is relatively small except for speeds of 125 rpm and lower.

6.3 The graphs indicate a resonance at about 200 rpm. Principal evidence is the sudden reduction in vibration amplitude and the corresponding phase shift. The three minor peaks on the amplitude curve may suggest three resonances but the absence of major phase shift suggests otherwise.

6.4 One of the reasons for presenting the Bodé plot is to show the phase shift. This may be used in calculating where the first trial weight should be located in a balancing program.

6.5 Figure 10 shows the undamped critical speed map which shows a first mode critical speed of 83 rpm, based on generator guide bearing stiffness G_x = Gy of 0.1 x 10^6 lb/in. Figure 11 shows unbalance response which is another presentation for the same analytical model. More details may be found in/2/ Section 3.

7.0 SHAFT ORBITS

7.1 Figure 12 shows shaft orbits, the motion of the journal in the bearing, for the generator guide bearing. These were taken from the generator guide bearing on July 15, 1986 when the seasonal cycle was near its peak, see Figure 1. The upper graphs are unfiltered, the lower ones are filtered at 1X shaft frequency.

7.2 The upper left orbit shows that there is only a small portion of the signal which is not 1X. We would expect a gross distortion of flattening of the orbit if the shaft runs tight against the bearing for a considerable part of the revolution. This would be caused if the shaft does not run quite in the centre of the bearing, and in part of the orbit uses up all the clearance on the small clearance side. This is important because it could indicate bearing distress. A slight "flat" may be present on the upper left orbit just to the right of the top-dead-centre.

7.3 The timebase graphs on the upper right show a higher frequency component which is not an exact multiple of 1X. There is a progressive change of shape over about 3 revolutions. Note the shape of the peaks and troughs of the waveform. This is more noticeable on the east probe. A guess at the higher frequency is 2.7X or 607 cycles/minute which agrees fairly well with the higher frequency peak of Figure 11.

7.4 Figure 13 shows a number of orbits taken at different times. The magnification is slightly smaller for the 15 Jul 86 orbit, and there was a gross change of magnification beginning 15 Dec 86. There seems to be no significant seasonal change in orbit shape related to the seasonal change in amplitude.

8.0 MODE SHAPE

8.1 Figure 14 gives an indication of the mode shape. Unfortunately three points are too few to give a highly reliable curve. The centreline of the guide bearing is slightly above the centreline of the probe as shown in the generator cross section of Figure 15. From Figures 14 and 15 it is inferred that the deflection at the bearing is slightly larger than the deflection indicated by the probes. The amount of difference is probably small, but it cannot be accurately estimated because of the uncertainties of the exact shape of the deflection curve of Figure 14 in the neighbourhood of the guide bearing. This detail is introduced because it may have an influence in determining the permissible shaft vibration level.

9.0 **BEARING TEMPERATURES**

9.1 The DDM does not measure guide bearing metal temperature, only thrust bearing metal temperature. Standard station instrumentation measures both. The following comparative readings were obtained from the Control Room Operator, Al Green for Units G4 and G5 on October 15, 1986 at 2:30 pm.

Unit	Metal Temperatures, degrees C	
	Thurst Bearing	Guide Bearing
G4	79	62
G5	80	81

9.2 The above readings suggest that the high temperatures on the G5 bearings may be due to losses arising from high guide bearing loads resulting from the high levels of shaft vibration.

10.0 **VIBRATION LIMITS FOR GENERATOR GUIDE BEARING SHAFT VIBRATION**

10.1 Three vibration limits are illustrated in Figure 16 from /3, 4, and 5/. Some notes on their application follow.

10.2.1 VDI qualifies the limit line as defined in the caption but they translate Führungslagern as thrust bearing. (I believe that Führungslagern should be translated "guide bearing" - there is no connotation of thrust for the word Führung but there is a dictionary translation of guide or guiding.) Based on that translation the VDI caption would read "Limit values for relative shaft vibration in the guide bearings of hydraulic machine sets. Derived from available data, for stationary operation within the guarantee range of efficiency of the hydraulic machine."

10.2.2 VDI gives clarification for errors in measurement due to "eccentricity, out-of-roundness, notches, scores, local residual magnetism or differences in the structure of the shaft material along the circumference." (Bently Nevada would call this "electrical runout", "mechanical runout", or "glitch".) VDI says "Their absolute magnitude should not exceed 35% of the values of the limit curve of" Figure 16.

10.2.3 VDI at their Section 6.2 give a long description of "Evaluation of Shaft Vibration" including some guidelines for operation under transient conditions and outside the guarantee range.

10.2.4 VDI says that Figure 16 "is valid for all kinds of hydraulic machines independent of the type, pressure and power; however with the restrictions made in Section 2. For hydromechanically less problematic turbine types, such as Peltonturbines or double regulated Kaplanturbines, normally lower shaft vibration must be expected." (Section 2 indicates that is applicable to large machines over 1 MW but excludes sets if one or more of the main machines have ball bearings or if the plain bearing surfaces are of rubber or plastics.)

10.3 The Hydro-Quebec reference says the limit line separates zones of "Planned Correction" and "Immediate Correction" as noted in Figure 16.

10.4.1 The NEMA standard, though rescinded, may have been rescinded for reasons other than the section on runout levels. (I have no information.) Some notes from the standard are quoted below:

"---, the runout at the guide bearings of the combined shaft shall be checked with the unit running at normal speed and rated load with [dial] indicators mounted on the bearing supports. The unit shall be considered as meeting the requirements of this standard if the runout (exclusive of skate*) does not exceed 70 to 80% of the diametrical clearance in the guide bearings and if the temperature of the guide bearings does not exceed 75°C.

"* Skate is the lateral random movement of a shaft superimposed on the periodic runout. This movement may be up to the full clearance of the bearing and is generally not considered significant in an analysis of shaft motion."

10.4.2 The chain line shown on Figure 16 has been drawn at 80% of the measured bearing clearance of 21 mils ie 16.8 mils.

10.5 The actual values of "Alert" and "Danger" for generator and turbine bearings as set on the DDM at SAB1 Unit G5 are plotted by * and • respectively.

10.6 The NEMA limit value may apply to the Maximum Total Vibration shown in Figure 3. The NEMA MG 5.2 limit line is somewhat artificially horizontal. The horizontal axis--nominal shaft speed--implies different designs. With higher shaft speed designs, a reduction in design bearing clearance would bring the higher speed part of the limit line down.

10.7 Whichever criterion is used it is clear that SAB1 Unit G5 is in poor shape and should be improved before another seasonal peak is experienced.

11.0 RECOMMENDED WORK AND TEST PROGRAM

11.1 Estimate the amount and angle of the first trial correction to be applied from present readings and past experience on balancing Unit G4 and G5, and prepare suitable correction weights.

11.2 Evaluate the effect of bearing oil temeprature by restricting thrust bearing cooling water flow, in steps, to the extent necessary to reach a bearing metal temperature of 80°C as was reached in the summer of 1986. Then return cooling flow to normal.

11.3 Confirm some characteristics included in this report, particularly to confirm that the DDM system angle measurements are similar to those obtained in August 1985 by the Automatic Diagnostics for Rotating Equipment (ADRE). To do this the DDM system should be deployed in the most efficient manner to collect results. Some changes to the configuration, particularly gain ranges and frequency of readings, should be made.

11.4 Confirm magnetic unbalance by taking readings at full load, 80% load, and 60% load, and zero load. Also take zero load readings, not excited.

11.5 Confirm the Bodé plot of Figure 9 by taking readings at 240, 225, 205, 190, 175, 100 and 75 rpm.

11.6 Shut down, and apply balance weight.

11.7 Follow the reverse procedure during loading, with the proviso that another balance correction may be required if the first shot does not produce the expected improvement.

11.8 Note that because of the already reported magnetic unbalance it is likely that vibration levels at speed but not excited will be higher than they are at present, the improved--balanced--condition will result only when excitation is returned.

11.9 During the work and test procedure a running check and plot of vibration results similar to Figure 8 should be maintained to confirm that changes and improvements follow the expected pattern.

11.10 If these recommendations are accepted a more detailed test plan and schedule should be prepared.

12.0 CONCLUSION

Present seasonal high generator guide bearing shaft vibration levels are unacceptably high. The machine can be made to run much smoother by improving the balance. This would reduce the hazard of bearing failure, and hence a long forced outage.

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1. Boyd, J.M. and Bosmans, R.F., "Monitoring for Predictive Maintenance in Hydropower Plants" 14th Inter-Ram Conference for the Electric Power Industry, Toronto, Canada, May 26-29, 1987.

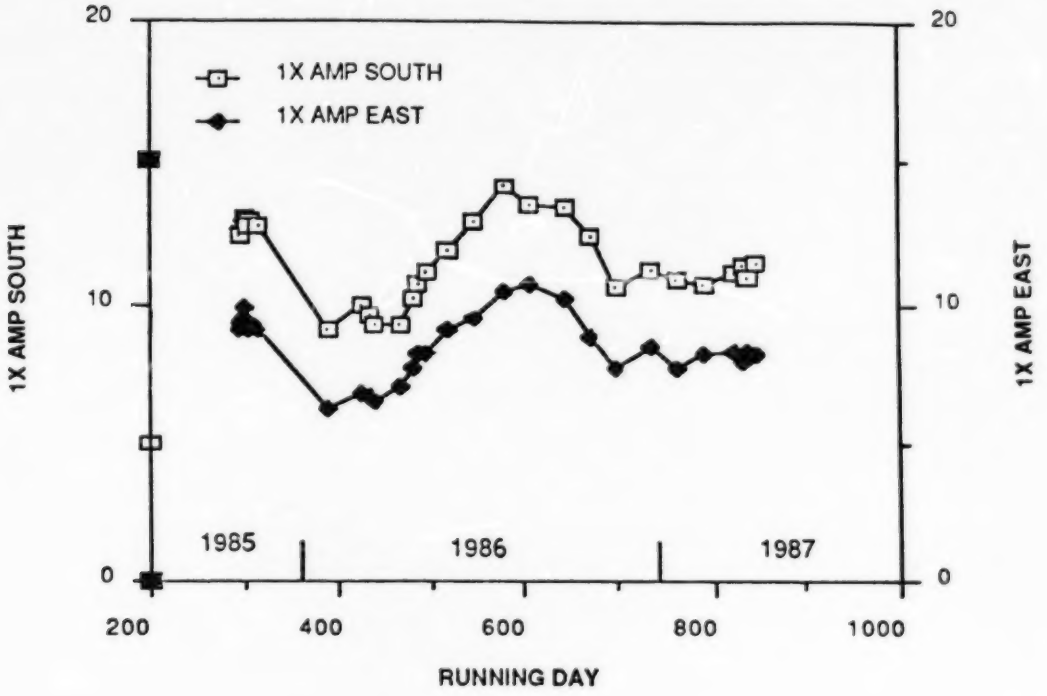
2. Koehler, H.P., Boyd, J.M., and Bosmans, R., "Monitoring for Predictive Maintenance of Hydropower Plants" Preliminary Draft of Final Report, 86-11-26. (This report is unpublished. Much of the detail applicable to shaft vibration of SAB1 Unit G5 was removed in the editing of the final EPRI report).

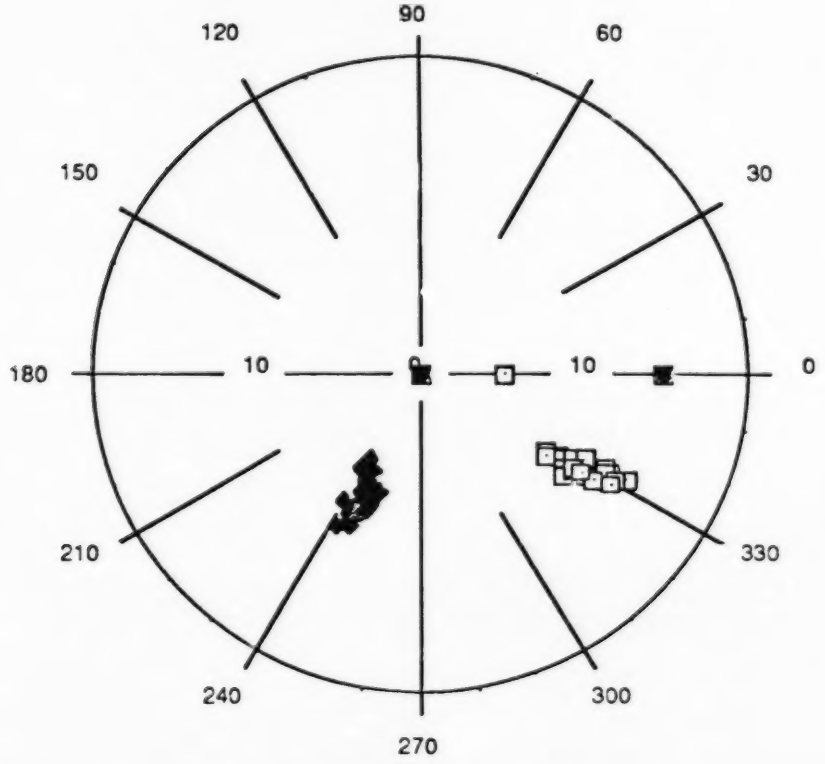
3. Verein Deutscher Ingenieure. "Shaft Vibration of Hydraulic Machine Sets: Principles of Measurement and Evaluation" VDI 2059 Part 5, October 1982.

4. Henry Day. "Practical Applications of the Measurement and Control of Vibrations in Hydraulic Turbines." Hydro Quebec, University of Virginia Short Course on "Vibration in Pumps and Hydraulic Turbines.' August 21, 1984.

5. National Electric Manufacturers Association. "Installation of Vertical Hydraulic-Turbine-Driven Generators and Reversible Generator/Motors for Pumped Storage Installations." Pub. No MG 5.2 1972 (Revised October 10, 1975: Reconfirmed 1977: But Rescinded Nov 1983).

Data from "SAB1 GEN GUI BEARING DATA"





SAB1 GENERATOR GUIDE BEARING VIBRATION SEASONAL VARIATION
FIGURE 1

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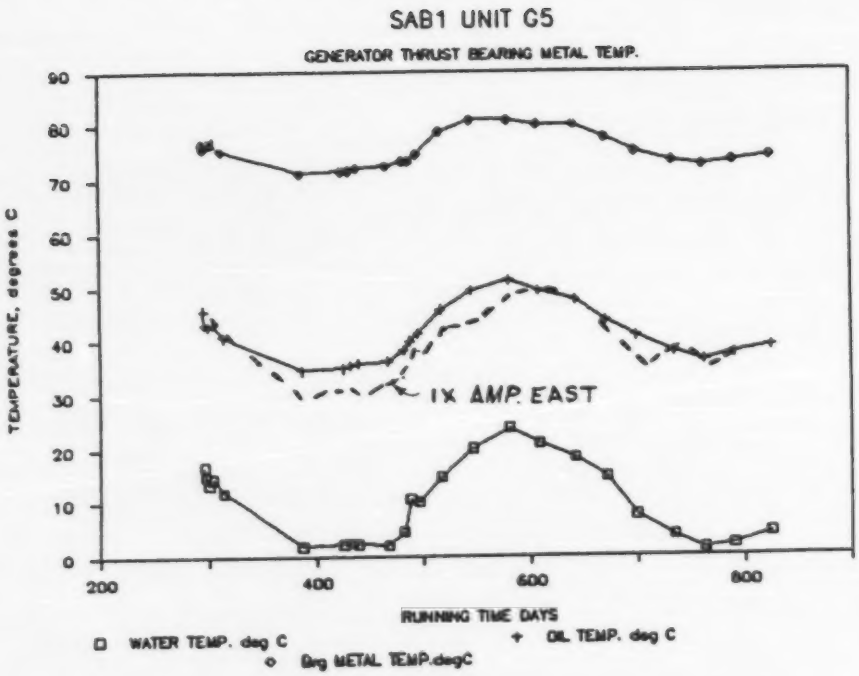
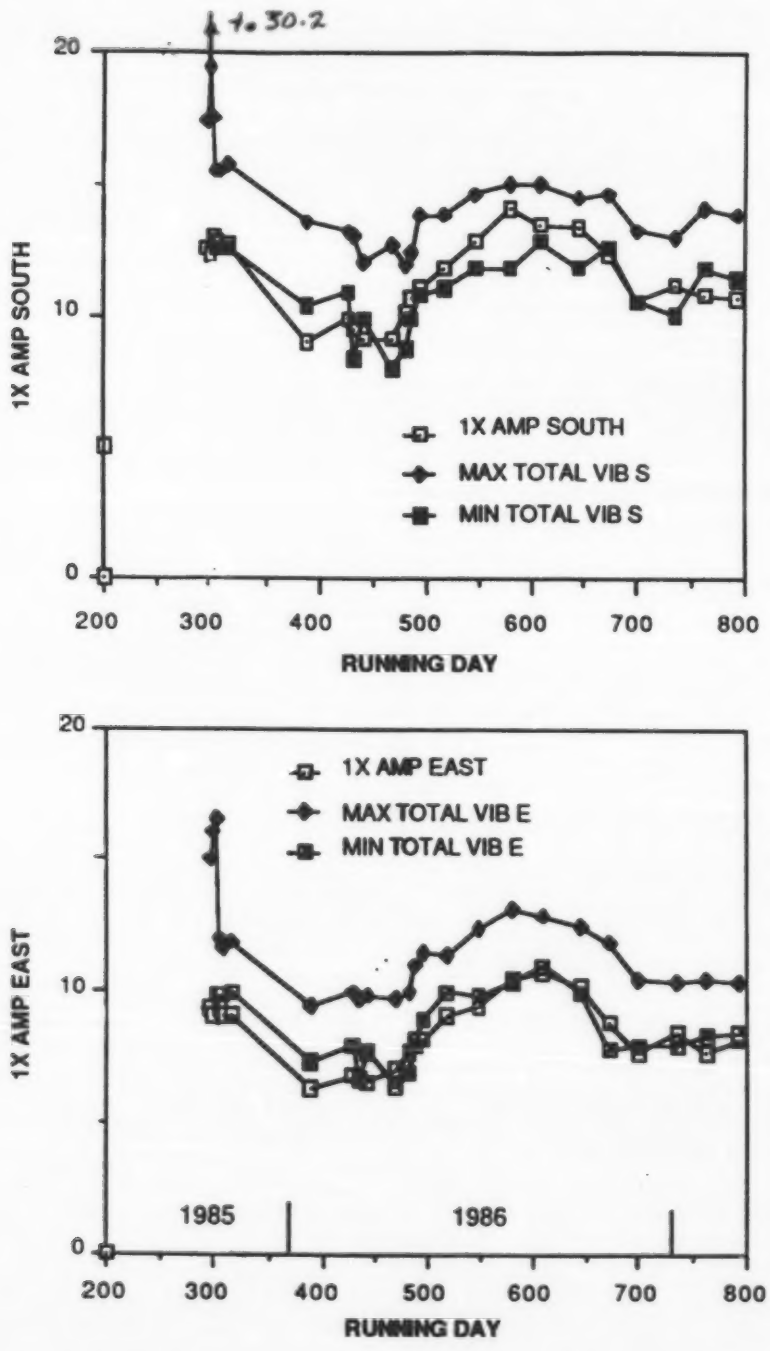


FIGURE 2. GENERATOR THRUST BEARING METAL TEMPERATURE VS TIME

Data from "SAB1 GEN GUI BEARING DATA"



SAB 1 UNIT G5

GENERATOR GUIDE BEARING VIBRATION

FIGURE 3. FILTERED AND UNFILTERED VIBRATION LEVELS COMPARED

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APR 2 1987

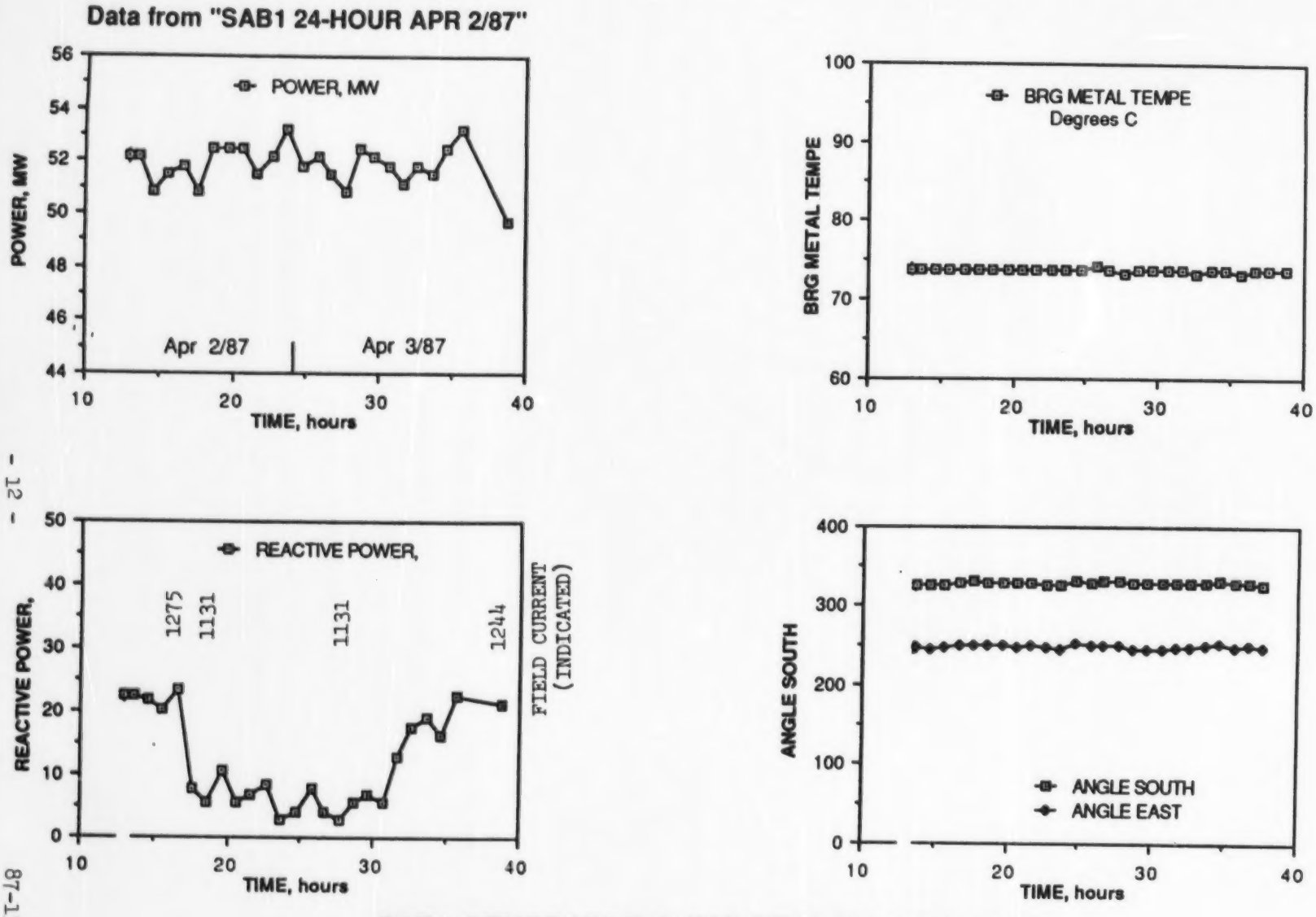

FIGURE 4. 24-HOUR MEASUREMENTS - PROCESS VARIABLES

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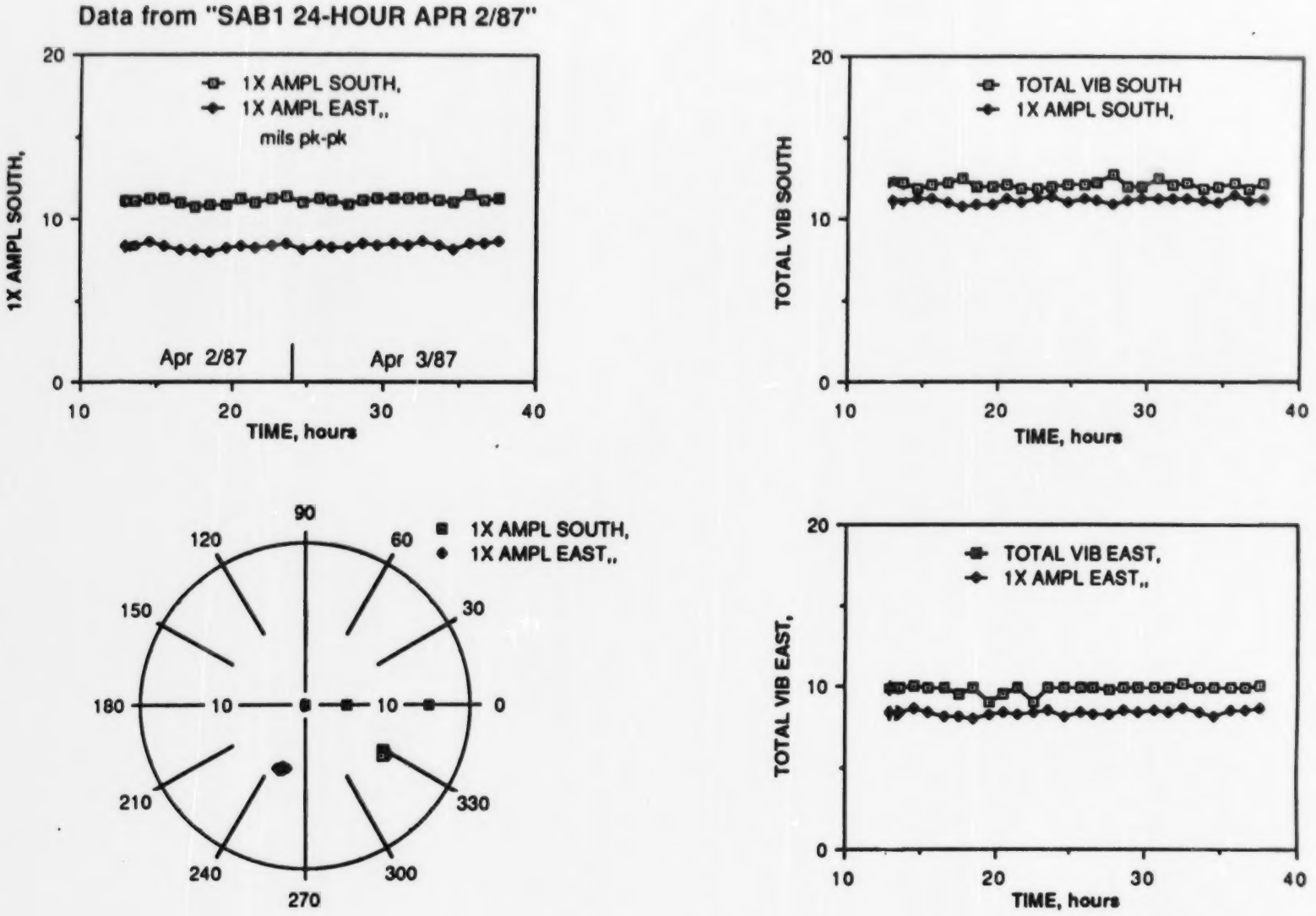

SAB1 GENERATOR GUIDE BEARING VIBRATION

FIGURE 5. 24-HOUR MEASUREMENTS - VIBRATION

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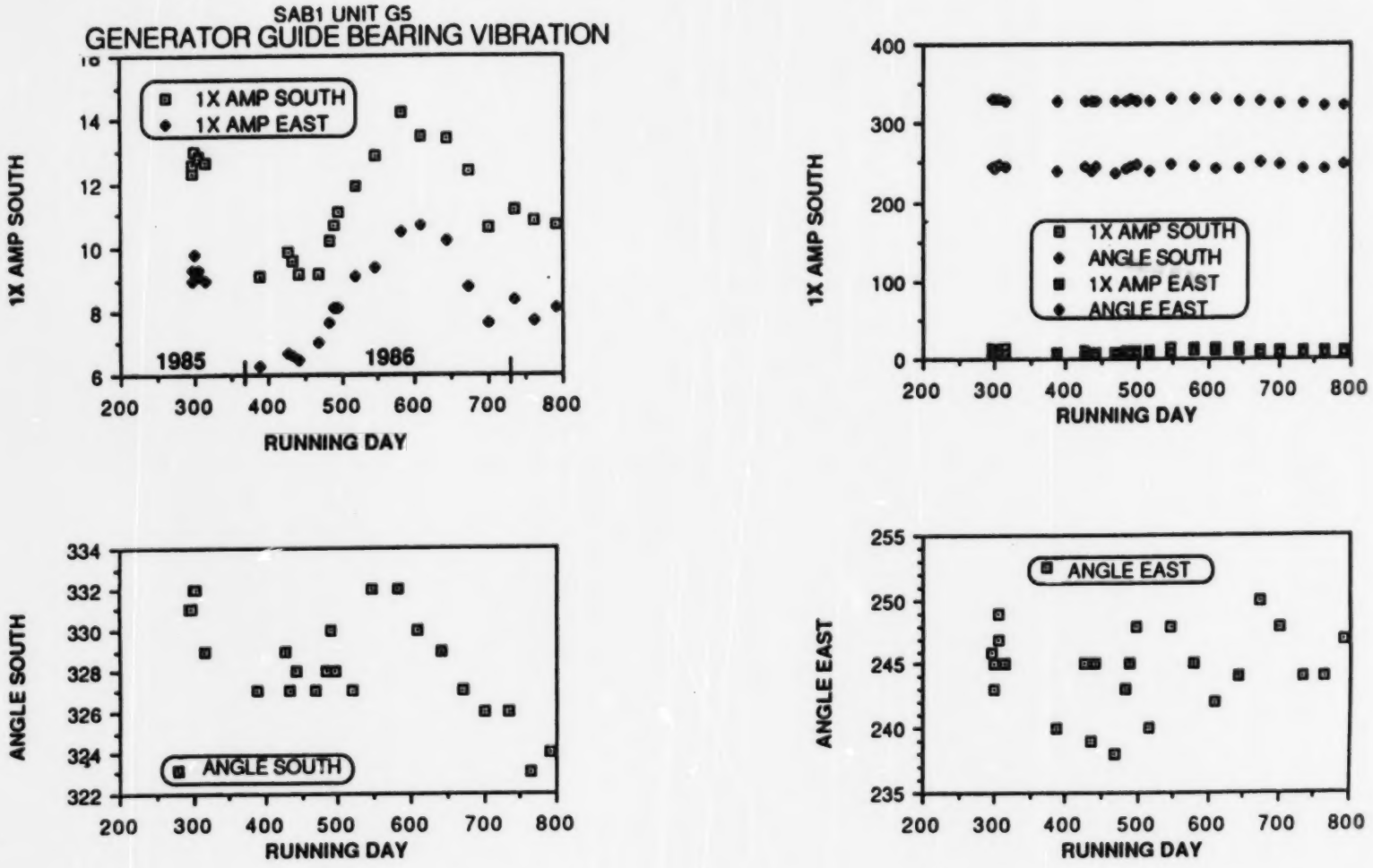

FIGURE 6. LONG TERM TRENDS OF VIBRATION PHASE

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MAR 3 1 1

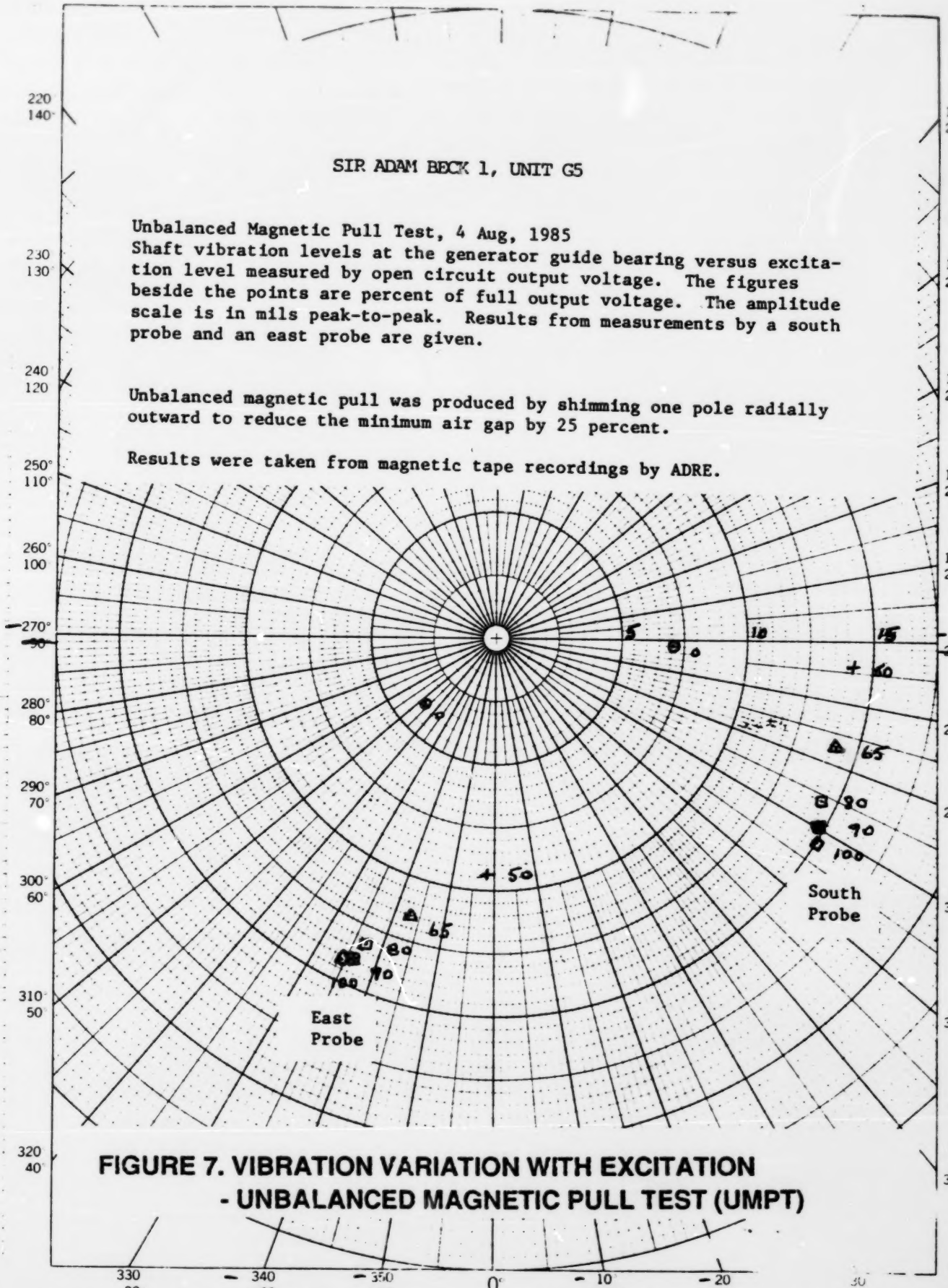
SIR ADAM BECK 1, UNIT G5
Unbalanced Magnetic Pull Test, 4 Aug, 1985
Shaft vibration levels at the generator guide bearing versus excitation level measured by open circuit output voltage. The figures beside the points are percent of full output voltage. The amplitude scale is in mils peak-to-peak. Results from measurements by a south probe and an east probe are given.
Unbalanced magnetic pull was produced by shimming one pole radially outward to reduce the minimum air gap by 25 percent.
Results were taken from magnetic tape recordings by ADRE.
South Probe
East Probe
46 4412
K·E POLAR CO-ORDINATE

FIGURE 7. VIBRATION VARIATION WITH EXCITATION - UNBALANCED MAGNETIC PULL TEST (UMPT)

87-139

SIR ADAM BECK 1, UNIT G5

Normal Open Circuit Test, 6 Aug, 1985

Shaft vibration levels at the generator guide bearing versus excitation level measured by open circuit output voltage. The figures beside the points are percent of full output voltage. The amplitude scale is in mils peak-to-peak. Results from a south probe and east probe are given

Results were taken from magnetic tape recordings by ADRE.

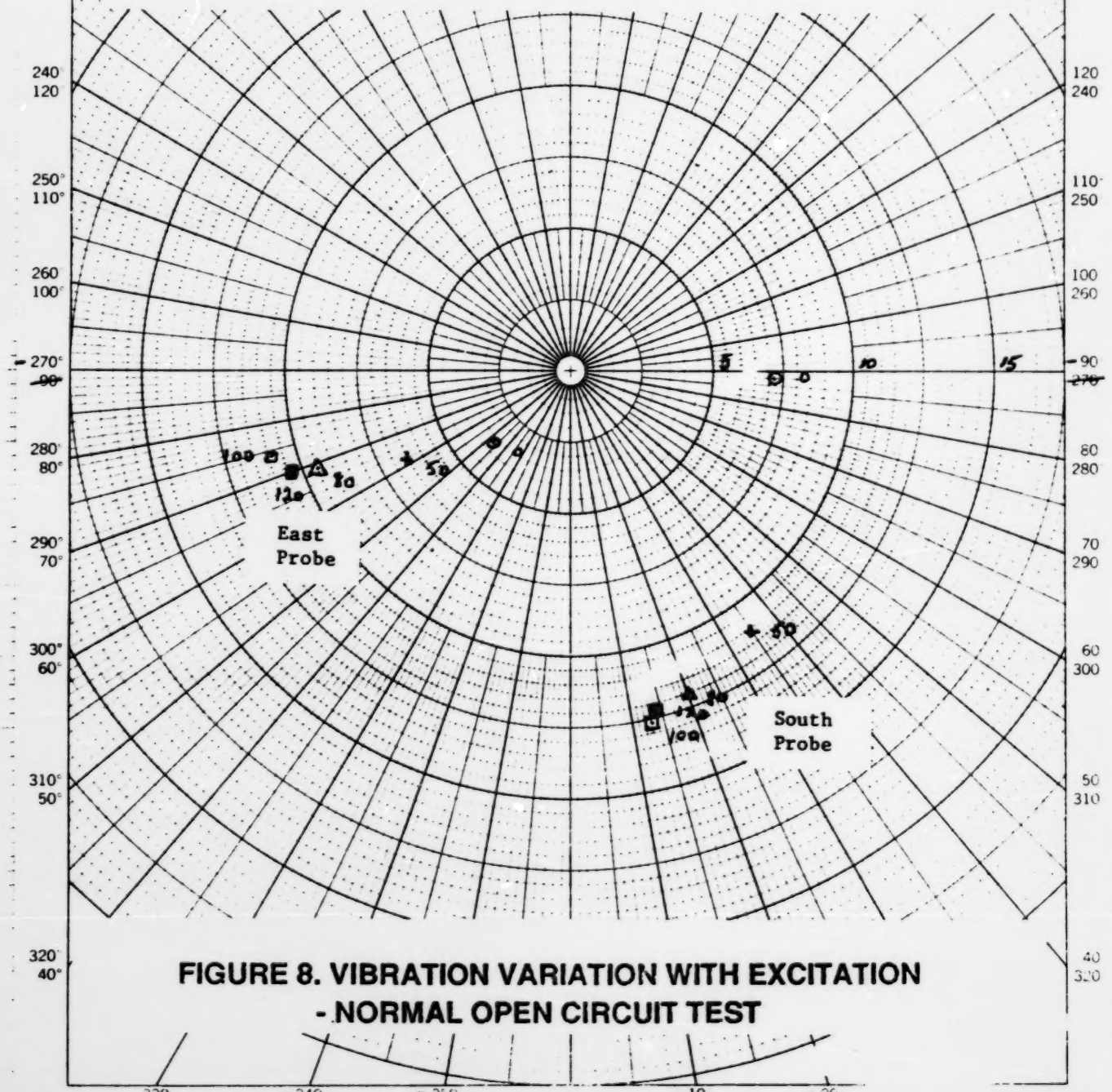

FIGURE 8. VIBRATION VARIATION WITH EXCITATION - NORMAL OPEN CIRCUIT TEST

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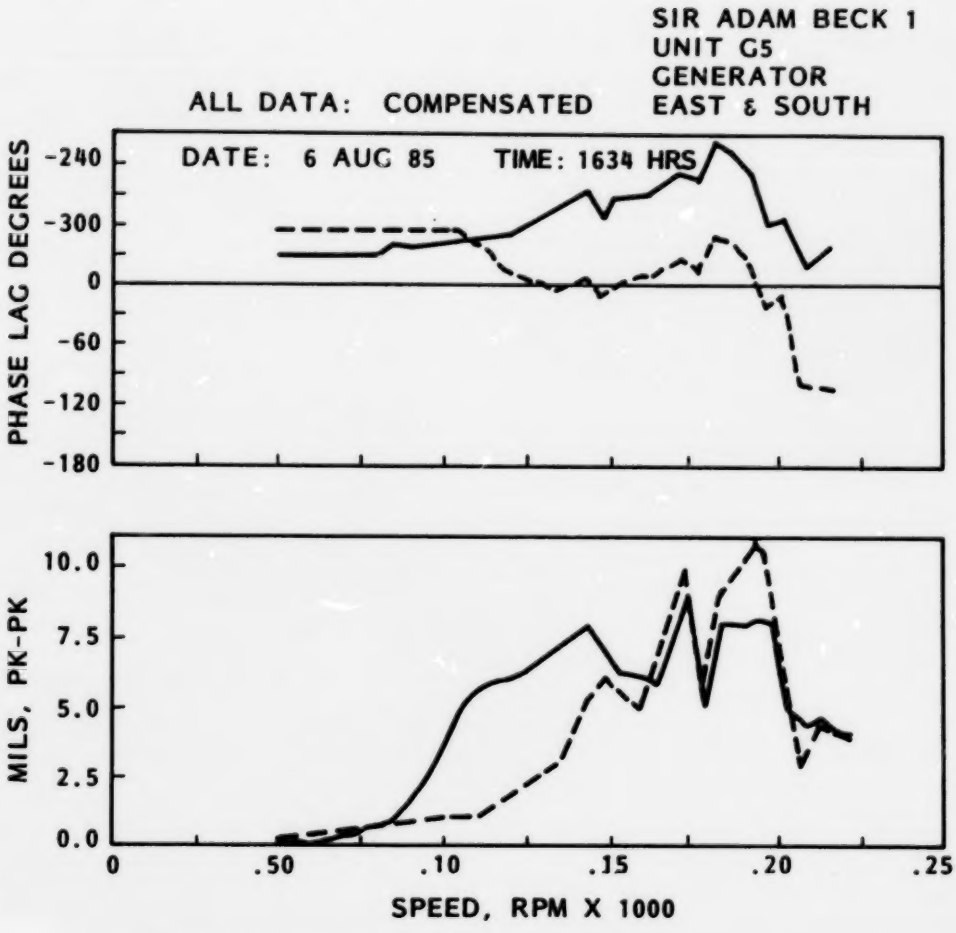


VECTOR(S) SUBTRACTED FROM DATA: 1.5 @ -185 SOUTH
SLOW ROLL (mils,pk-pk) 50 RPM 1.3 @ -78 EAST

DATA TAKEN ON SHUT DOWN JUST AFTER OPEN CIRCUIT TEST

FIGURE 9

BODÉ PLOT FOR SHAFT VIBRATION AT GENERATOR GUIDE BEARING

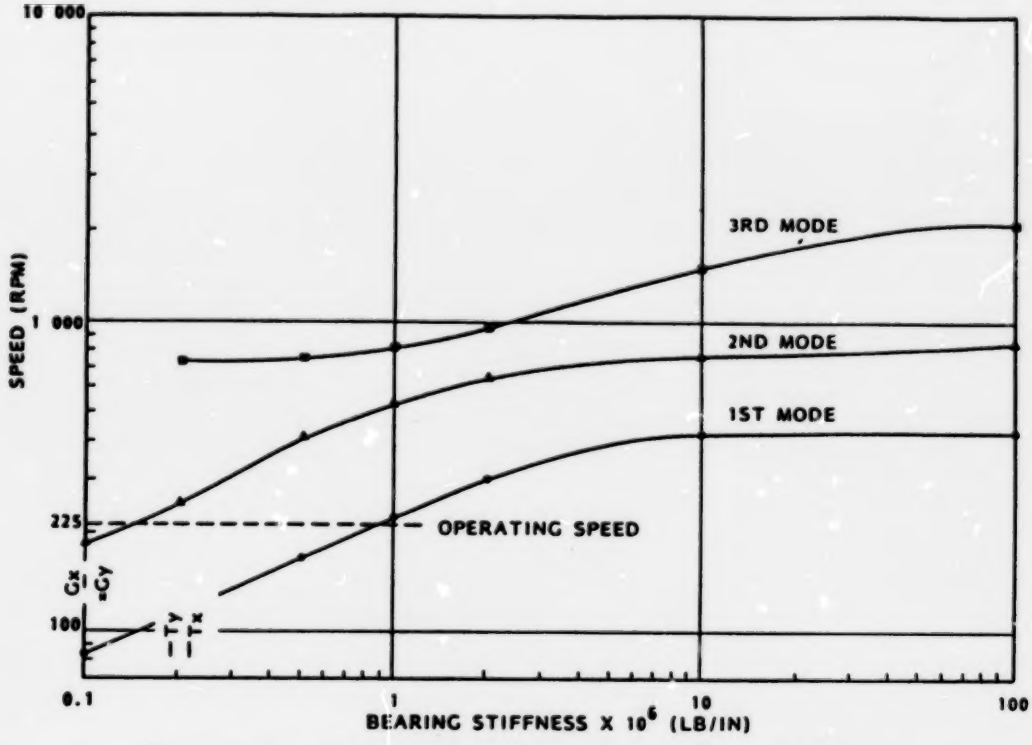


Figure 10. Undamped Critical Speed Map, SAB1

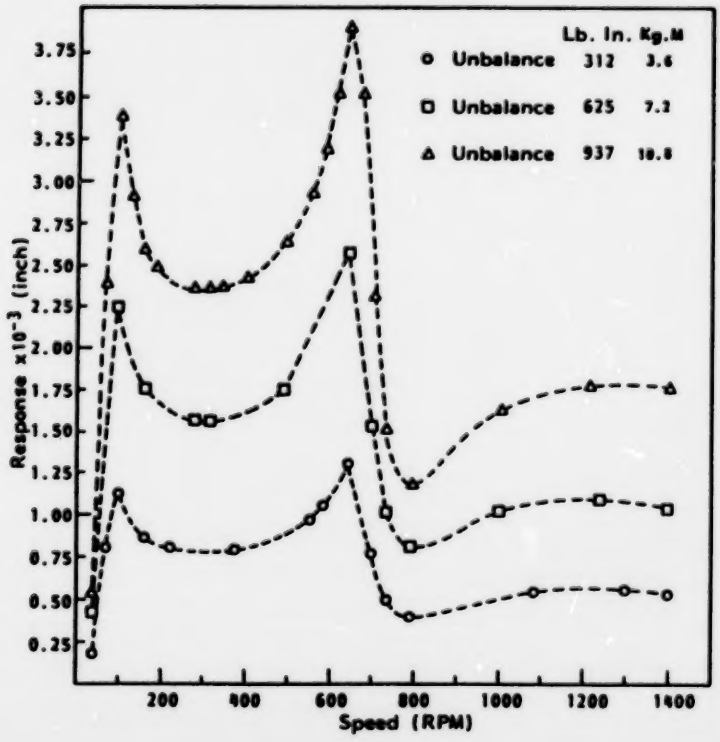
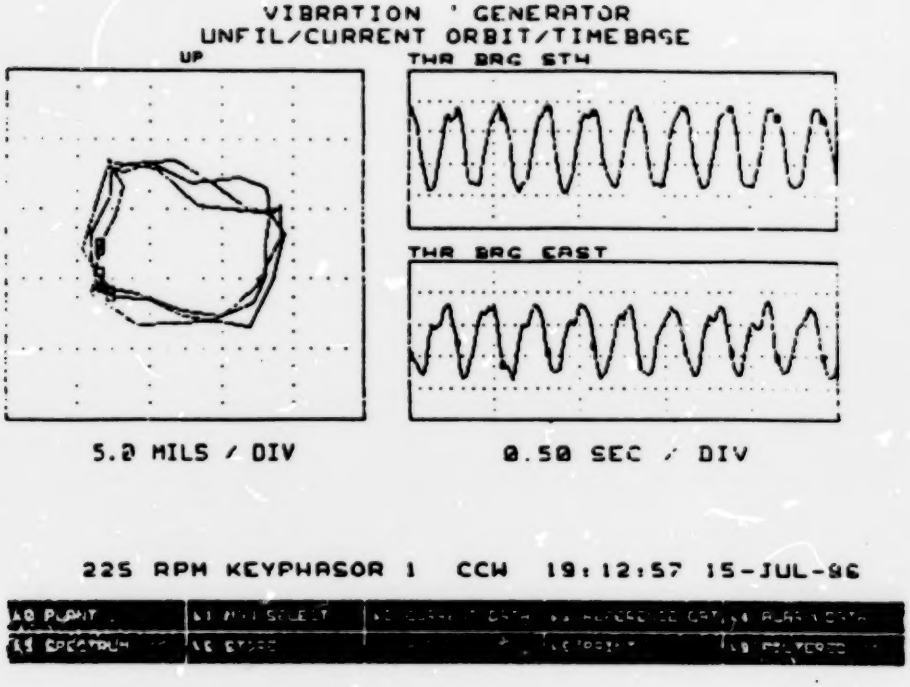


Figure 11. Generator Mass Unbalance Response, SAB1 Unit G5 Measured at the Generator Guide Bearing



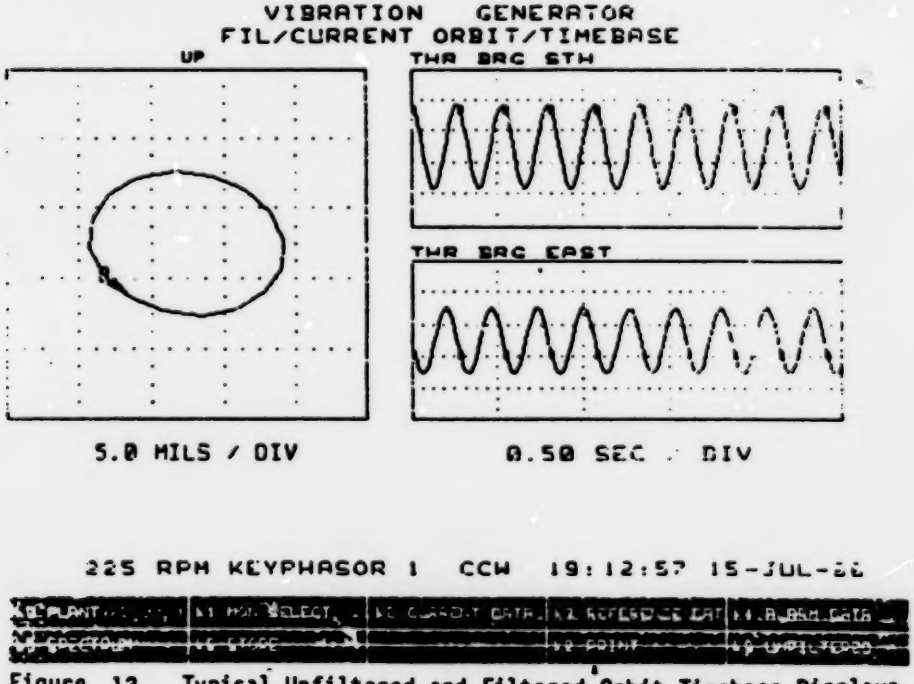


Figure 12. Typical Unfiltered and Filtered Orbit-Timebase Displays

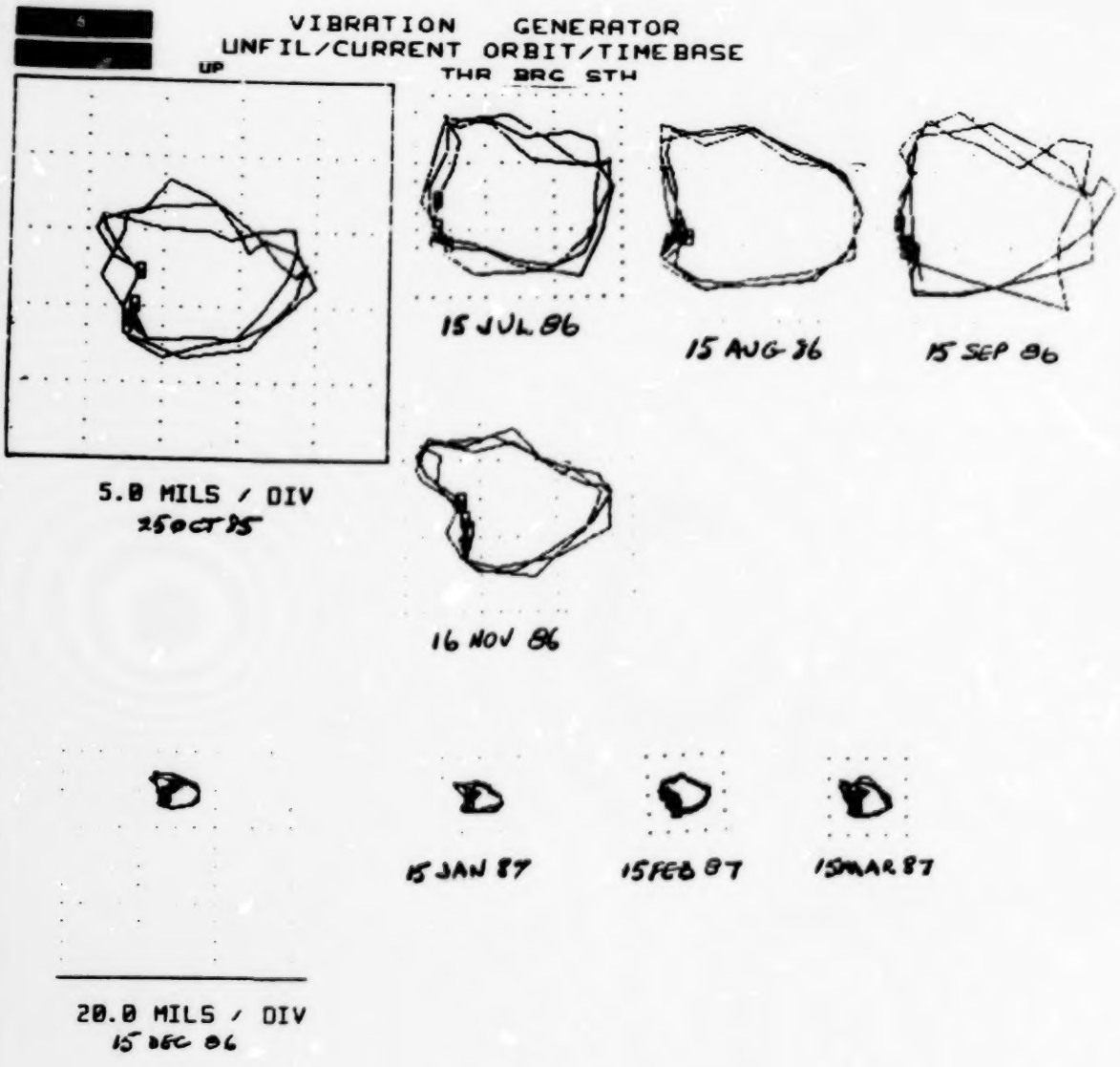


FIGURE 13. SHAFT ORBITS, LONG TERM TRENDS

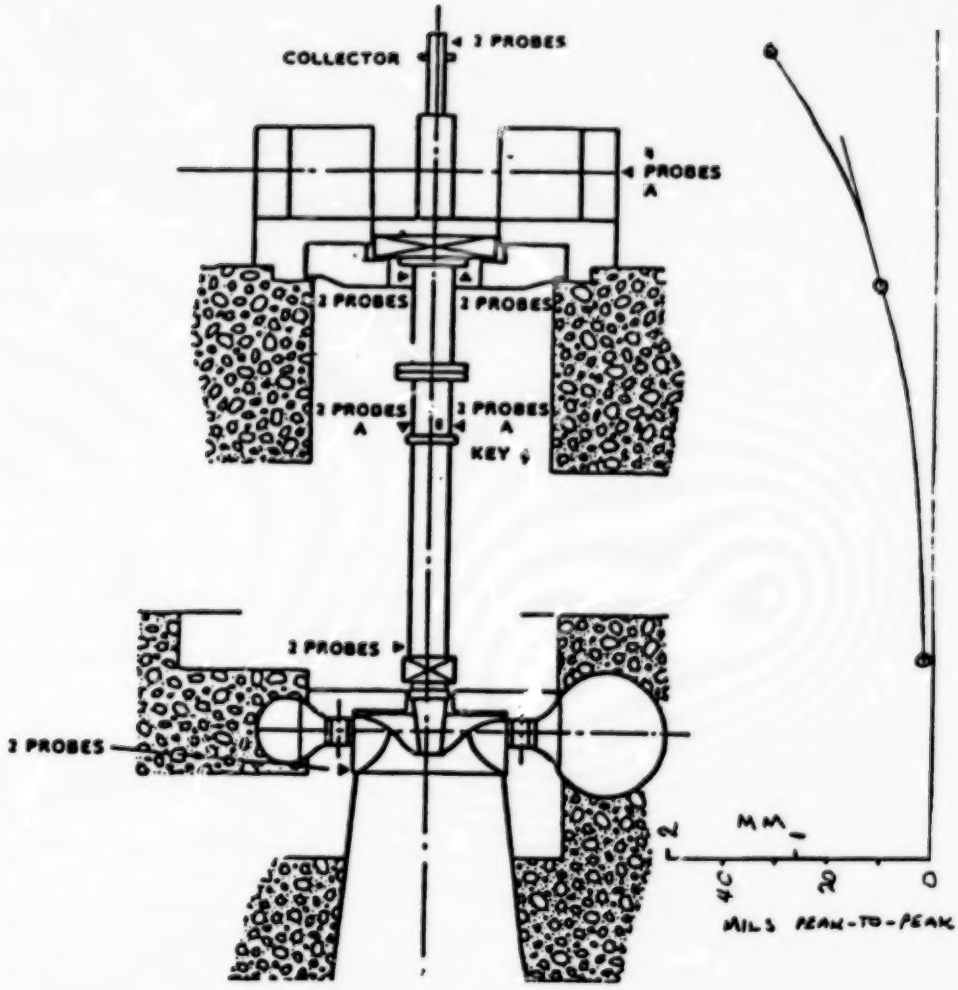


FIGURE 14. MODE SHAPE

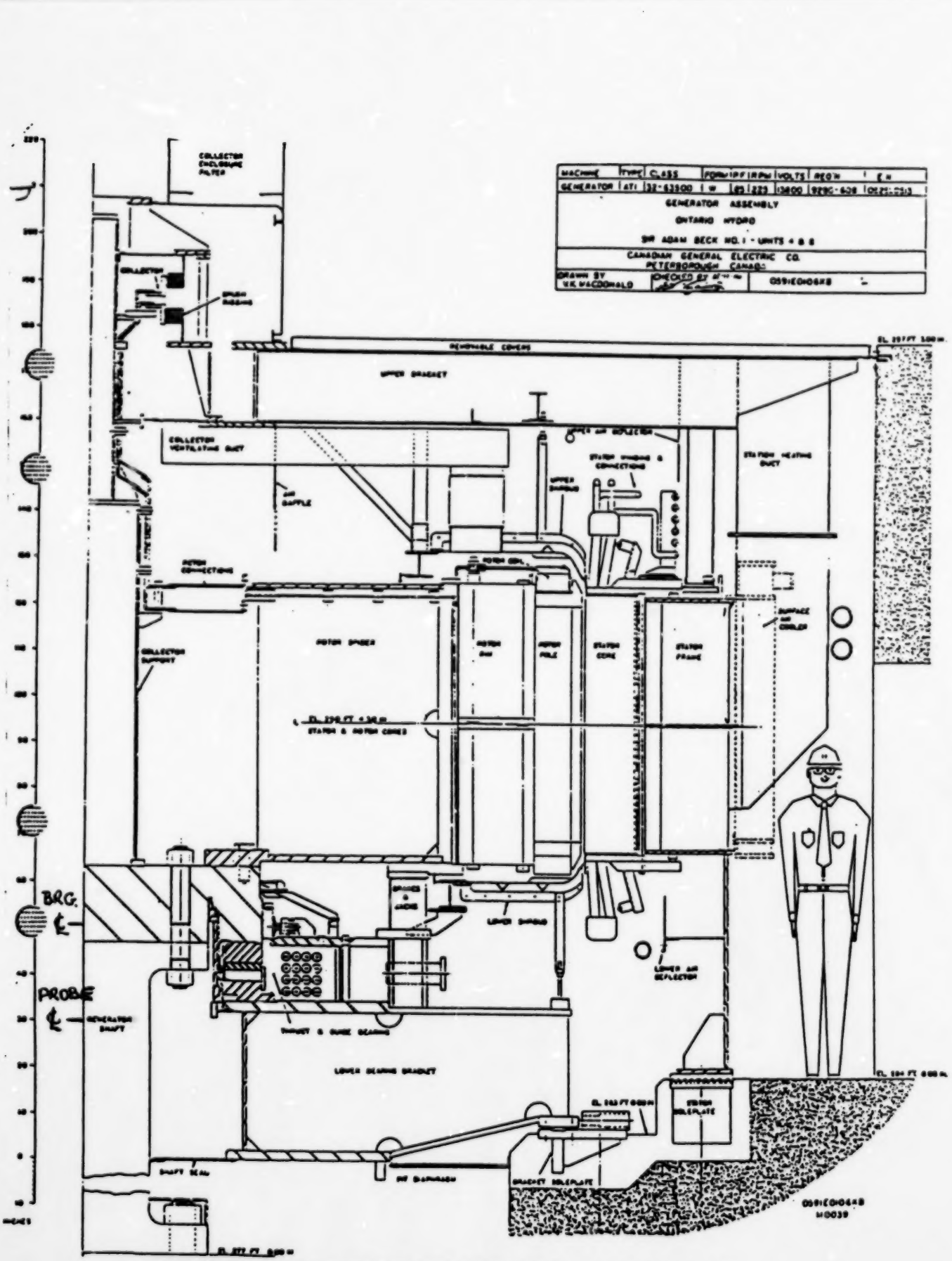


FIGURE 15. GENERATOR GENERAL ASSEMBLY SHOWING BEARING AND PROBE LOCATIONS

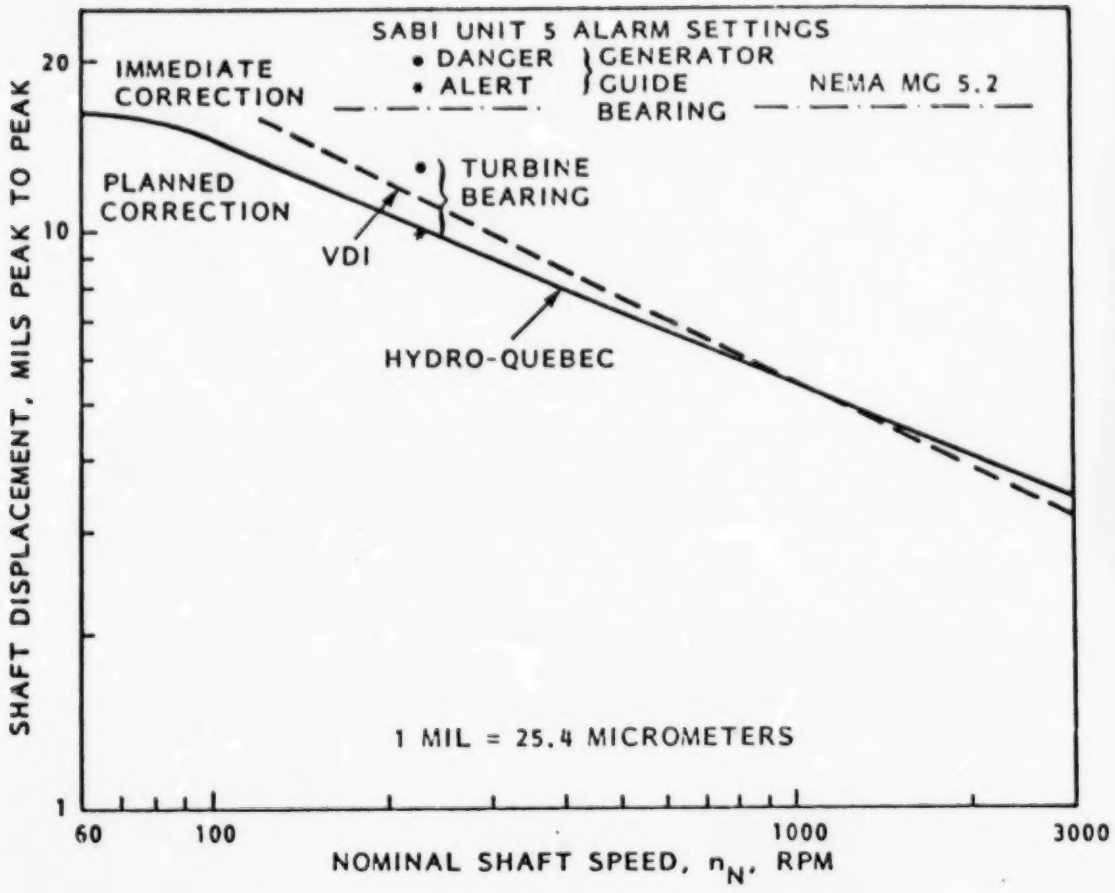


Figure 16. Limit Values for Relative Shaft Vibration of Hydraulic Power Machines

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